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Grant et al.

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(54) **COMPRESSED NATURAL GAS FUEL MASS CONTROL SYSTEM**

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F02M 69/00 (2006.01)
F02M 21/02 (2006.01)
F02D 19/02 (2006.01)

(52) **U.S. Cl.**
CPC ***F02M 69/00*** (2013.01); ***F02D 19/02*** (2013.01); ***F02M 21/02*** (2013.01); ***F02M 21/023*** (2013.01); ***F02M 21/0218*** (2013.01); ***F02M 21/0236*** (2013.01); ***F02M 21/0239*** (2013.01); *Y02T 10/32* (2013.01)

(58) **Field of Classification Search**
CPC ... F02M 69/00; F02M 21/02; F02M 21/0218; F02M 21/023; F02M 21/0287; F02M 21/06; F02M 21/0239
USPC .... 123/445, 527, 27 GE, 464, 465, 577, 123/41.05, 41.08, 41.136, 41.31, 540, 541, 123/543, 557, 525, 553, 554, 552, 555, 123/545; 62/48.1; 165/293, 292, 297
See application file for complete search history.

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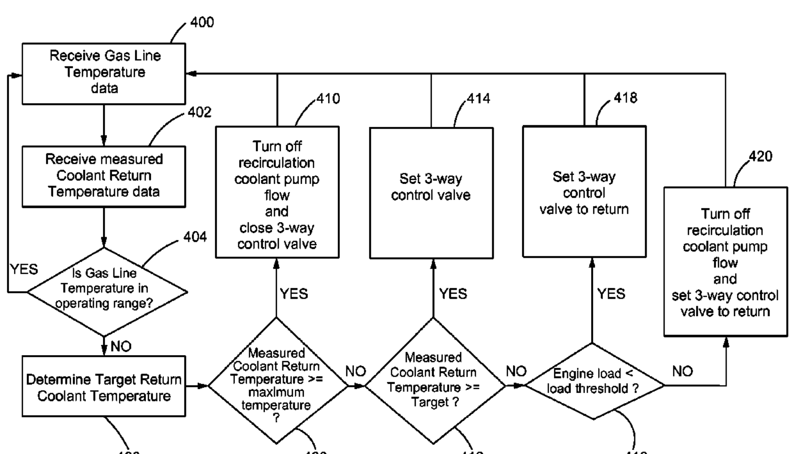
(57) **ABSTRACT**

A system, related method and computer program product are disclosed for controlling fuel mass of CNG received by an engine. The system may comprise a heat exchanger configured to receive CLNG and supply coolant and to output CNG and return coolant, an injector configured to inject CNG into the engine, a gas line between the injector and heat exchanger, a control valve configured to receive return coolant from the heat exchanger and to change the amount of return coolant flowing through control valve, and a controller connected to the control valve. The gas line may be configured to carry CNG from the heat exchanger to the injector. The controller may be configured to maintain a Gas Line Temperature within an operating range by adjusting the amount of return coolant flowing through the control valve based, at least in part, on the Gas Line Temperature and a Target Return Coolant Temperature.

18 Claims, 7 Drawing Sheets



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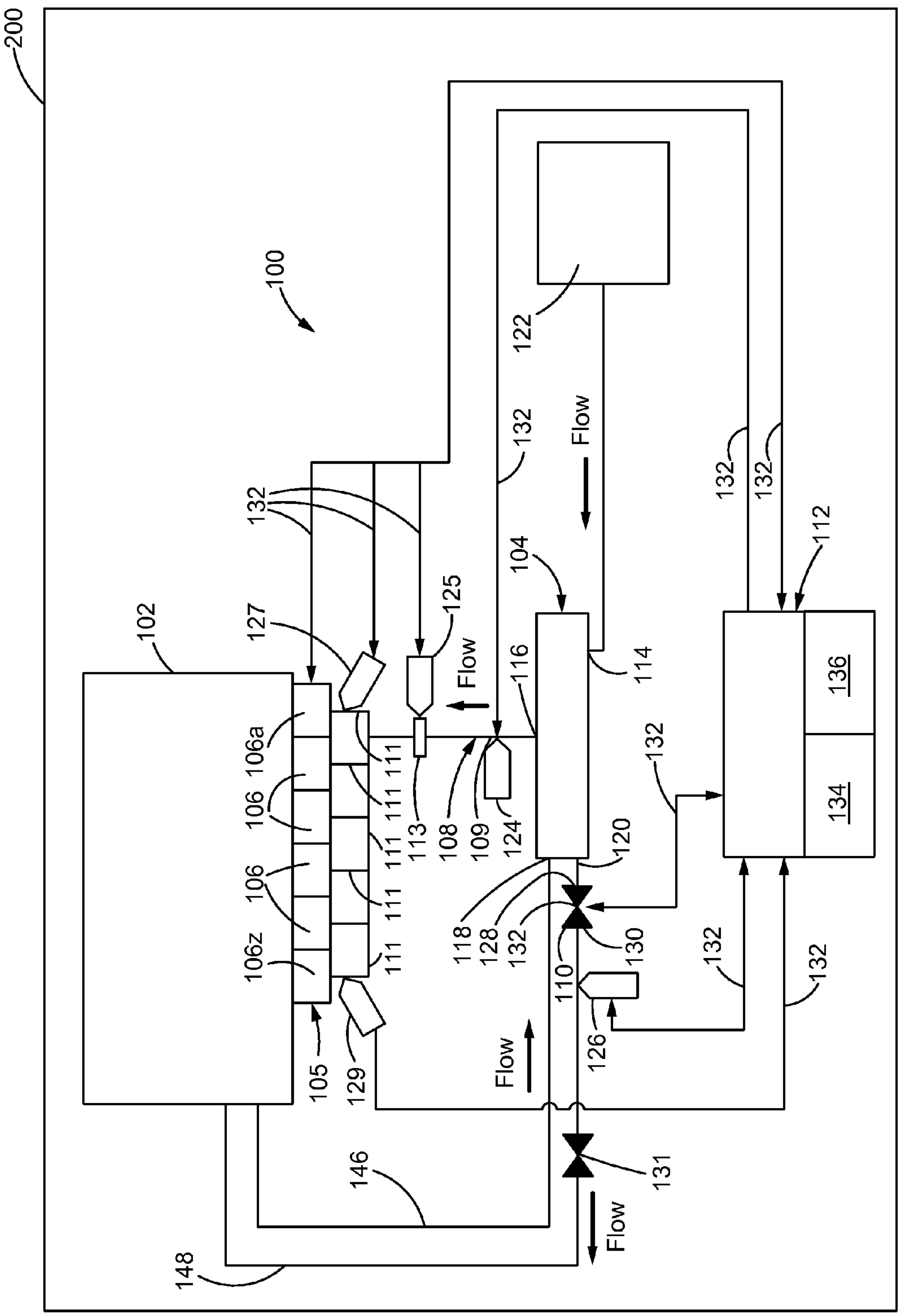
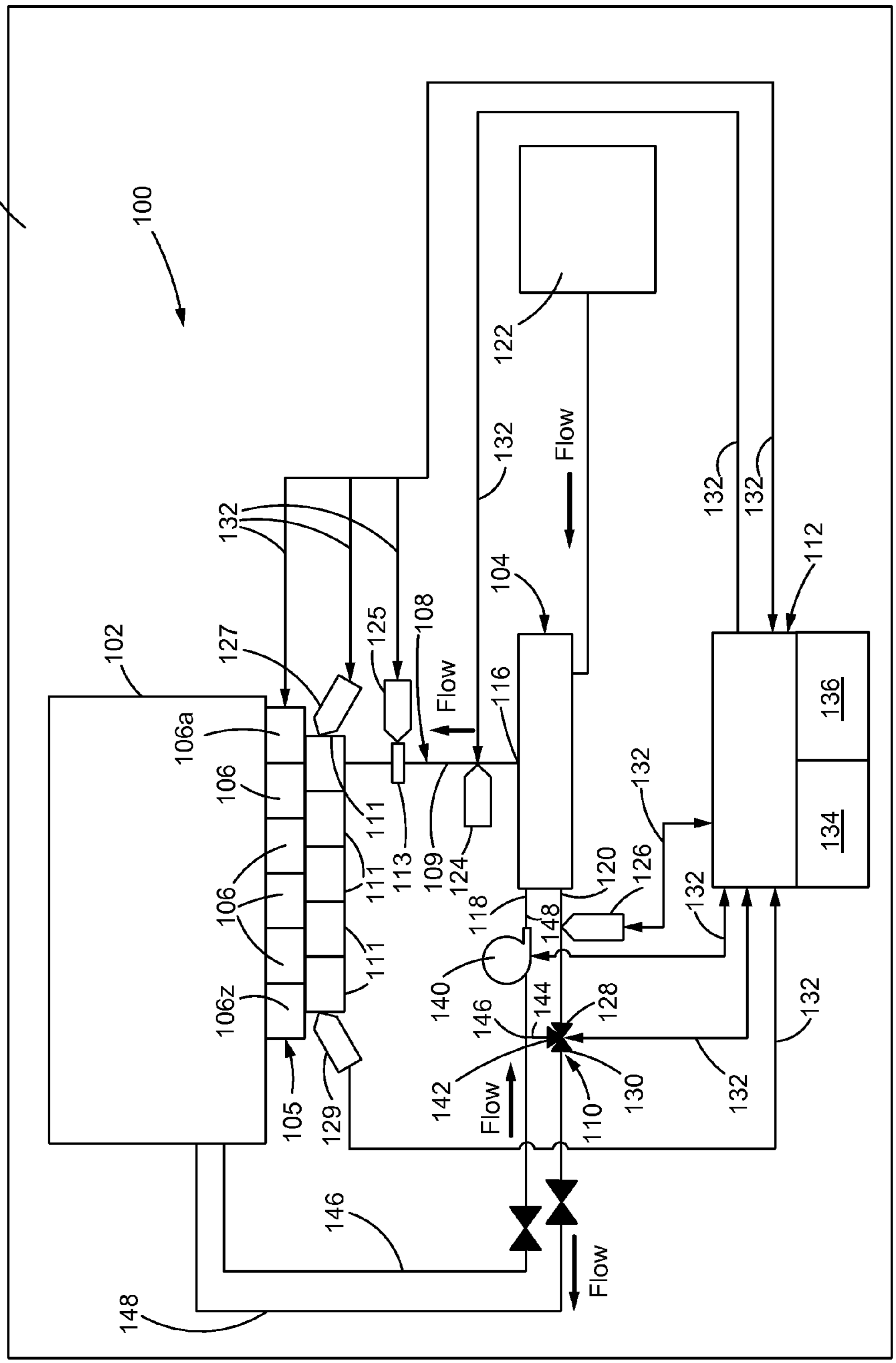

200
100
122
132
Flow
104
112
114
116
125
127
102
106a
106
106z
111
113
108
109
124
120
118
128
130
110
126
134
136
105
129
146
148
131

FIG. 1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129
Flow
146
148
Flow

FIG. 2

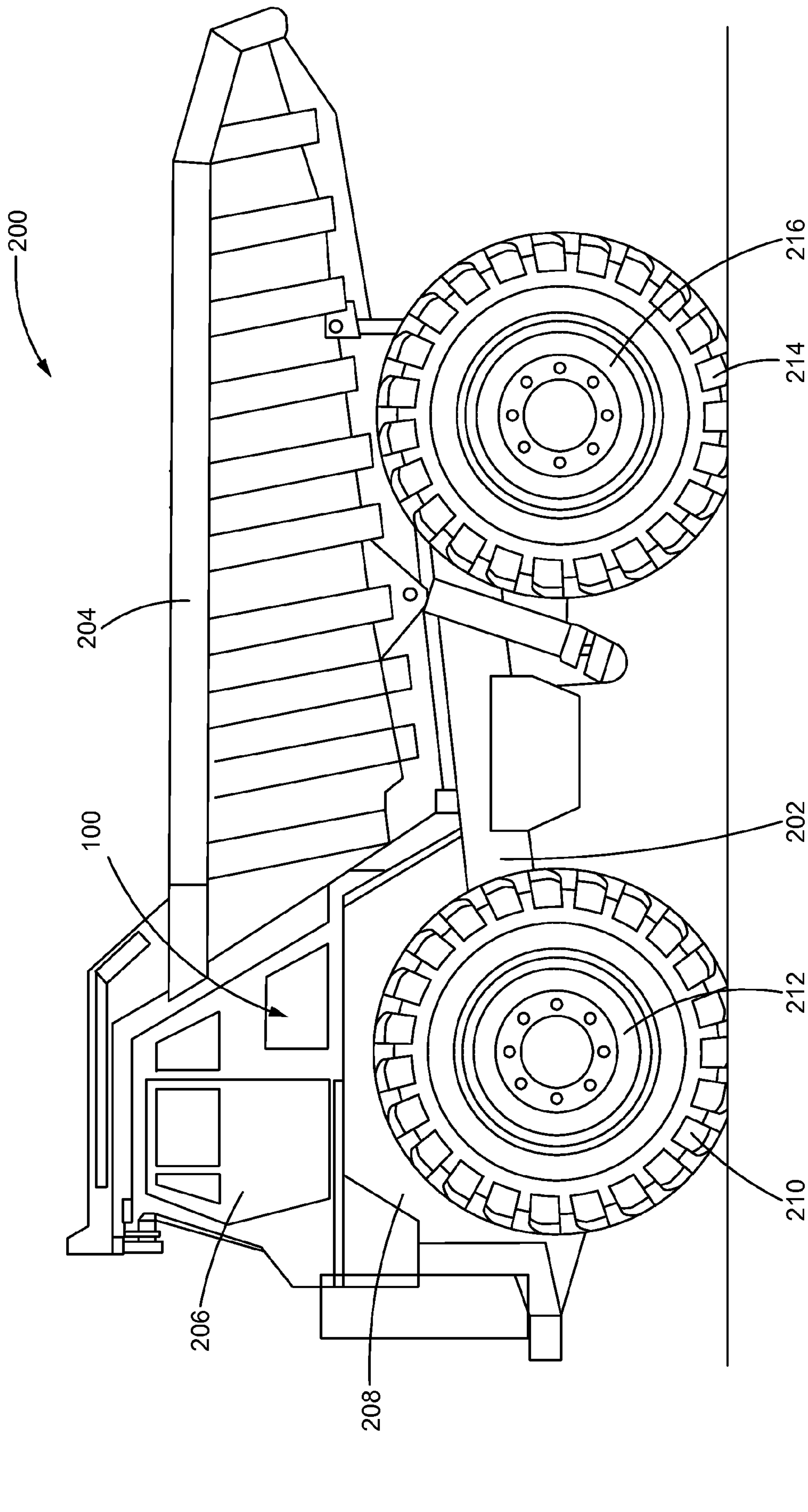

FIG. 3

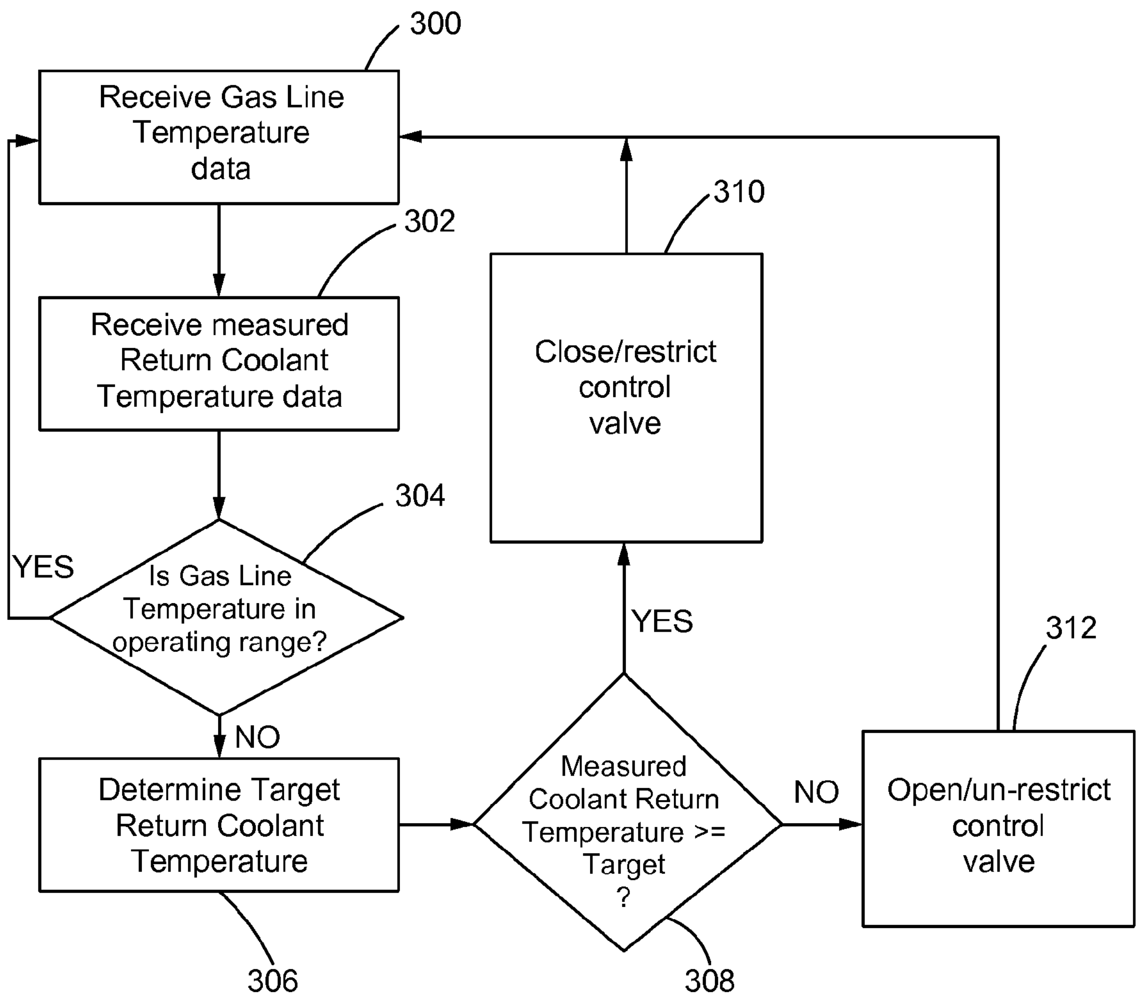
300
Receive Gas Line Temperature data
302
Receive measured Return Coolant Temperature data
304
Is Gas Line Temperature in operating range?
YES
NO
Determine Target Return Coolant Temperature
306
Measured Coolant Return Temperature >= Target ?
308
YES
NO
Close/restrict control valve
310
Open/un-restrict control valve
312

FIG. 4

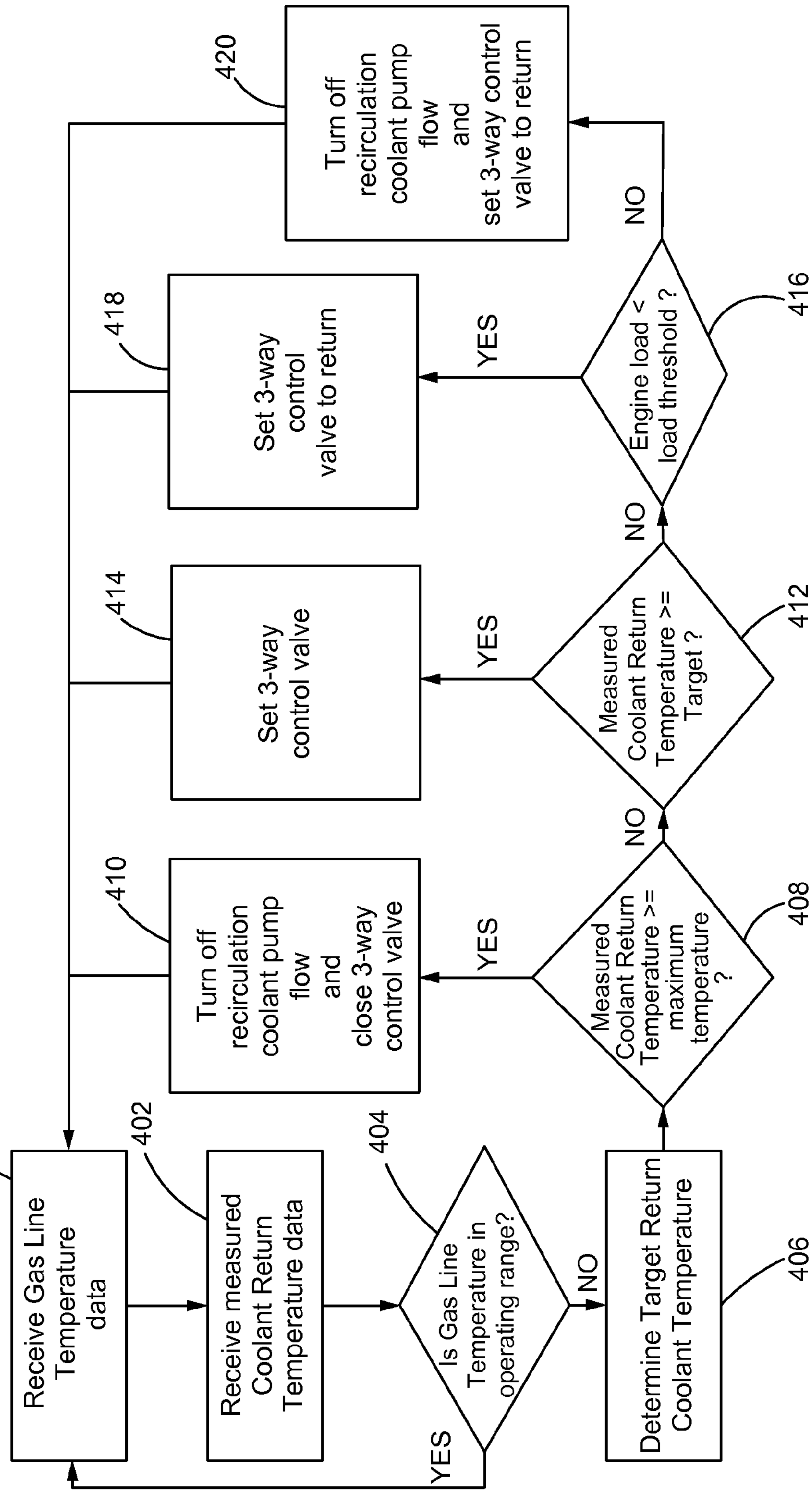
400
Receive Gas Line Temperature data
402
Receive measured Coolant Return Temperature data
404
Is Gas Line Temperature in operating range?
YES
NO
406
Determine Target Return Coolant Temperature
408
Measured Coolant Return Temperature >= maximum temperature ?
YES
410
Turn off recirculation coolant pump flow and close 3-way control valve
NO
412
Measured Coolant Return Temperature >= Target ?
YES
414
Set 3-way control valve
NO
416
Engine load < load threshold ?
YES
418
Set 3-way control valve to return
NO
420
Turn off recirculation coolant pump flow and set 3-way control valve to return

FIG. 5

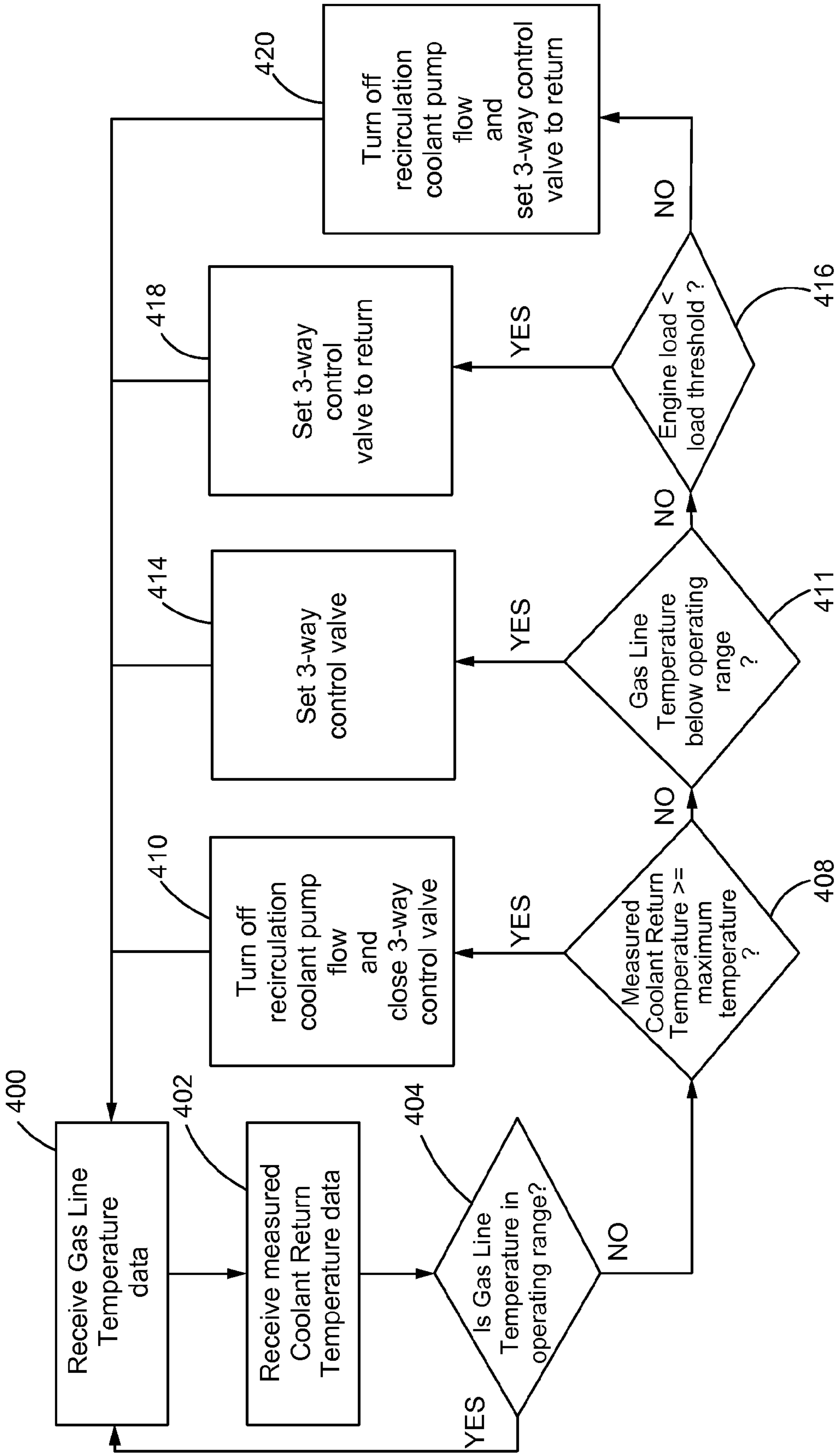
400
Receive Gas Line Temperature data
402
Receive measured Coolant Return Temperature data
404
Is Gas Line Temperature in operating range?
YES
NO
408
Measured Coolant Return Temperature >= maximum temperature ?
YES
NO
410
Turn off recirculation coolant pump flow and close 3-way control valve
411
Gas Line Temperature below operating range ?
YES
NO
414
Set 3-way control valve
416
Engine load < load threshold ?
YES
NO
418
Set 3-way control valve to return
420
Turn off recirculation coolant pump flow and set 3-way control valve to return

FIG. 6

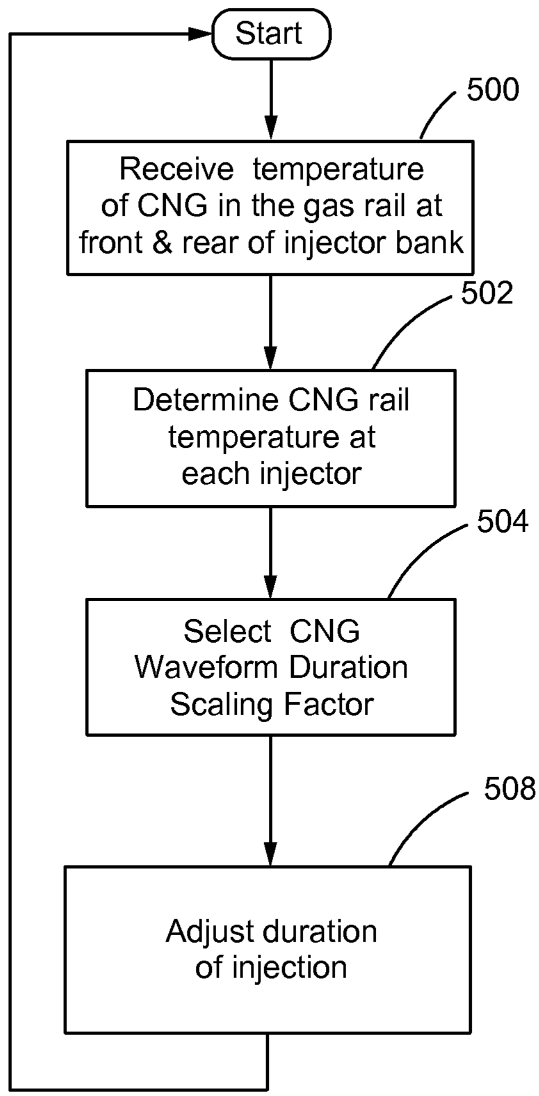
Start
500
Receive temperature of CNG in the gas rail at front & rear of injector bank
502
Determine CNG rail temperature at each injector
504
Select CNG Waveform Duration Scaling Factor
508
Adjust duration of injection

FIG. 7

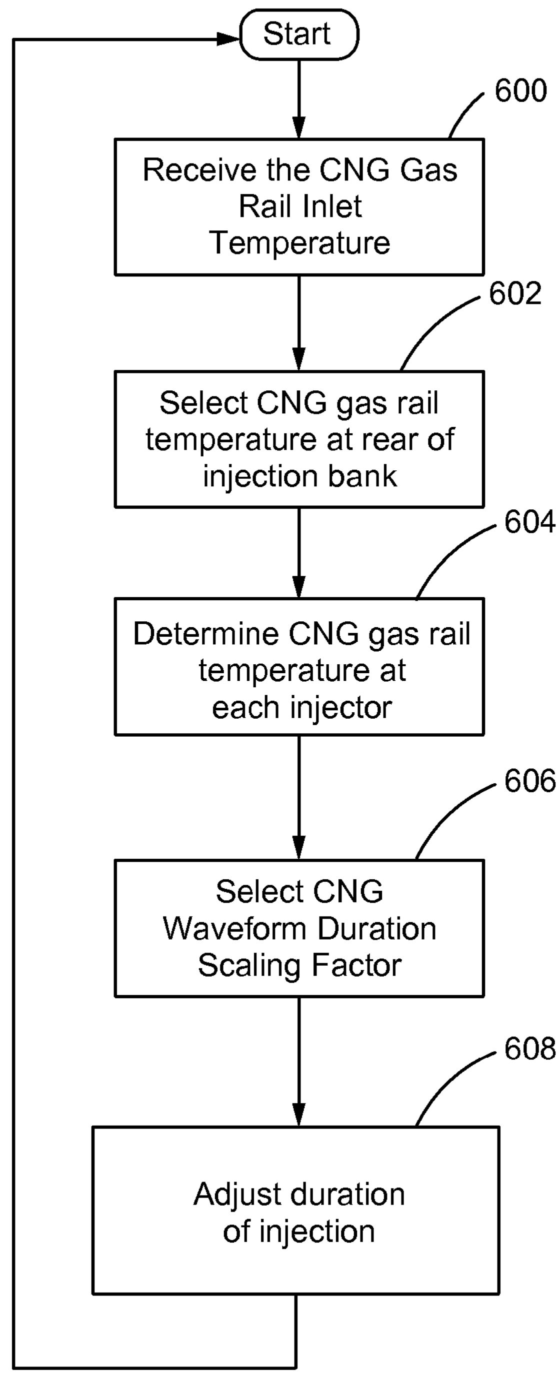
Start
600
Receive the CNG Gas Rail Inlet Temperature
602
Select CNG gas rail temperature at rear of injection bank
604
Determine CNG gas rail temperature at each injector
606
Select CNG Waveform Duration Scaling Factor
608
Adjust duration of injection

FIG. 8

COMPRESSED NATURAL GAS FUEL MASS CONTROL SYSTEM

TECHNICAL FIELD

The present disclosure generally relates to compressed natural gas systems on vehicles and, more particularly, relates to compressed natural gas systems on vehicles used in earth moving, construction, material handling, mining applications, and the like.

BACKGROUND

Vehicle applications using compressed natural gas systems often operate in variable environmental conditions and under changing operational modes. Changes in ambient temperature and changes in operational modes (idling, moving, loading, and the like) may effect the density of the fuel delivered to the engine by high pressure direct injection. Stable and consistent engine power output may be improved by controlling the fuel mass of the compressed natural gas delivered to the engine. Consistent fuel mass delivery provides a combustion environment that allows for stable power generation regardless of changing environmental or operational conditions.

U.S. Pat. No. 7,182,073 issued Feb. 27, 2007 (the '073 patent) discloses a liquefied petroleum gas injection engine system on a vehicle. The system disclosed seeks to lower emissions by reducing leakage of fuel into the intake system of the engine after the engine has been in an off condition. The '073 patent discloses an engine control management system electronic control unit that controls the injection time and injection rate of the liquefied petroleum gas injected through the injector depending on the traveling conditions of the vehicle, more specifically whether the fuel system receives natural cooling by outside air while the vehicle is moving or whether the vehicle is stopped and natural cooling of the air is unavailable. This type of system has drawbacks because the temperature of the fuel delivered may vary widely. A better system is needed.

SUMMARY OF THE DISCLOSURE

In accordance with one aspect of the disclosure, a method of controlling the fuel mass of compressed natural gas received by an engine is disclosed. The method may comprise receiving a Gas Line Temperature for compressed natural gas disposed in a gas line, and maintaining, by a controller operably connected to a control valve, the Gas Line Temperature within an operating range by adjusting the amount of return coolant allowed to flow through the control valve based at least in part on the Gas Line Temperature and a Target Return Coolant Temperature. In an embodiment, the gas line may be disposed between a heat exchanger and the engine, and the heat exchanger may be configured to receive compressed liquid natural gas and supply coolant and to output the compressed natural gas into the gas line and to output return coolant. The control valve may be configured to receive return coolant from the heat exchanger.

In accordance with another aspect of the disclosure, a system is disclosed. The system may comprise a heat exchanger configured to receive compressed liquid natural gas and supply coolant and to output compressed natural gas and return coolant, an injector operably connected to the engine and configured to inject the compressed natural gas into the engine, a gas line disposed between the injector and the heat exchanger, a control valve configured to receive return coolant from the heat exchanger and to change the amount of return coolant flowing through control valve, and a controller operably connected to the control valve. The gas line may be configured to carry compressed natural gas from the heat exchanger to the injector. The compressed natural gas in the gas line may be at a Gas Line Temperature. The controller may be configured to maintain the Gas Line Temperature within an operating range by adjusting the amount of return coolant allowed to flow through the control valve based, at least in part, on the Gas Line Temperature and a Target Return Coolant Temperature.

In accordance with a further aspect of the disclosure, a computer program product is disclosed. The computer program product may comprise a non-transitory computer usable medium having a computer readable program code embodied therein. The computer readable program code may be adapted to be executed to implement a method for controlling the fuel mass of compressed natural gas received by an engine, the method comprising receiving a Gas Line Temperature for compressed natural gas disposed in a gas line, and maintaining, by a controller operably connected to a control valve, the Gas Line Temperature within an operating range by adjusting the amount of return coolant allowed to flow through the control valve based at least in part on the Gas Line Temperature and a Target Return Coolant Temperature. In an embodiment, the gas line may be disposed between a heat exchanger and the engine, and the heat exchanger may be configured to receive compressed liquid natural gas and supply coolant and to output the compressed natural gas into the gas line and to output return coolant. The control valve may be configured to receive return coolant from the heat exchanger.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a general schematic view of an exemplary embodiment of a system constructed in accordance with the teachings of this disclosure;

FIG. **2** is general schematic view of another exemplary embodiment of a system constructed in accordance with the teachings of this disclosure;

FIG. **3** is perspective view of an exemplary vehicle in which the system of either FIG. **1** or **2** may be used;

FIG. **4** is flowchart illustrating exemplary steps of a method of controlling the fuel mass of compressed natural gas received by an engine in accordance with the teachings of this disclosure;

FIG. **5** is flowchart illustrating exemplary steps of a method of controlling the fuel mass of compressed natural gas received by an engine in accordance with the teachings of this disclosure;

FIG. **6** is flowchart illustrating exemplary steps of another method of controlling the fuel mass of compressed natural gas received by an engine in accordance with the teachings of this disclosure;

FIG. **7** is flowchart illustrating exemplary steps of a method of controlling the fuel mass of compressed natural gas received by an engine in accordance with the teachings of this disclosure; and

FIG. **8** is flowchart illustrating exemplary steps of a method of controlling the fuel mass of compressed natural gas received by an engine in accordance with the teachings of this disclosure.

DETAILED DESCRIPTION

Referring now to the drawings, and with specific reference to FIG. **1**, there is shown one embodiment of a system, generally referred to by reference numeral **100**, for controlling the fuel mass of compressed natural gas (CNG) received by an engine **102** in accordance with the present disclosure. The system **100** may comprise a heat exchanger **104**, a bank **105** including one or more injectors **106**, a CNG gas line **108**, a control valve **110**, a controller **112**, a supply channel **146** and a return channel **148**. The system may also include a gas line sensor **124** and a return coolant sensor **126**. Some embodiments may also include a gas rail inlet sensor **125**, a front temperature sensor **127** and a back temperature sensor **129**. In addition, some embodiments may include a flow orifice **131**.

While the following detailed description and drawings are made with reference to the system **100** mounted on a haul truck, the teachings of this disclosure may be employed on other mining, earth moving, construction, material handling, or the like vehicles. Such vehicles may be autonomously, semi-autonomously, or manually operated.

FIG. **3** illustrates one example of a vehicle **200** that incorporates the features of the present disclosure. The vehicle may be autonomous, that is remote controlled or having programmed movement, or may be semi-autonomous (having partially remote controlled or programmed functions), or may be manually operated. The vehicle **200** generally includes a main frame **202**, a dump body **204** pivotally mounted to the main frame **202**, and a cab **206** mounted on the front of the main frame **202** above an engine enclosure **208**. The vehicle **200** is supported on the ground by front tires **210** (one shown) each mounted on one of two front wheel assemblies **212**, and rear tires **214** (one shown) each mounted on one of two back (driven) wheel assemblies **216**. One or more engines (not shown) may be housed within the engine enclosure **208** to supply power to the drive wheel assemblies **216** via a mechanical or electric drive train.

Turning back to FIG. **1**, the heat exchanger **104** includes a first inlet **114**, a first outlet **116**, a second inlet **118** and a second outlet **120**. The heat exchanger **104** is configured to receive through the first inlet **114** compressed liquid natural gas (CLNG) from a fuel source **122** disposed on the vehicle **200**. The heat exchanger **104** is further configured to receive through the second inlet **118** supply coolant. The supply coolant may travel to the heat exchanger **104** through the supply channel **146**. In an embodiment, the supply coolant may include engine coolant. In another embodiment, the supply coolant may be only engine coolant received from the engine **102** through the supply channel **146**. The heat exchanger **104** is also configured to emit through the first outlet **116** CNG into the gas line **108** and to emit return coolant through the second outlet **120** into the return channel **148**. The return channel **148** may extend between the heat exchanger **104** and the engine **102**. The heat exchanger **104** may be any appropriate type of heat exchanger/vaporizer as is known in the art for heat transfer between a cold liquid (CLNG) and a warmer liquid (supply coolant).

The bank **105** includes a plurality of injectors **106**. Each injector **106** may be operably connected to the engine **102** and is configured to inject the CNG into the engine **102**, more specifically a combustion chamber (not shown) of the engine **102**.

The gas line **108** may be disposed between the injectors **106** and the heat exchanger **104**, and is configured to carry the CNG received from the heat exchanger **104** to the injectors **106**. The (CNG) gas line **108** may include a main line **109** portion and a gas rail **111** portion. The main line **109** may extend between the heat exchanger **104** and the gas rail **111**, and the gas rail **111** may extend between the main line **109** and the injectors **106**. The gas line **108** may also include a gas rail inlet **113** disposed at the interface of the main line **109** and the gas rail **111**.

The control valve **110** includes a first input port **128** and a first output port **130**.

The gas line sensor **124** is configured to measure the temperature of the CNG in the gas line **108** (the "Gas Line Temperature"). The return coolant sensor **126** is configured to measure the temperature of the return coolant (the "Return Coolant Temperature"). The return coolant sensor **126** may be disposed relatively close to the second outlet **120** of the heat exchanger **104** to better reflect the temperature of the coolant in the heat exchanger **104**.

In those embodiments in which the system **100** also includes the gas rail inlet sensor **125**, the gas rail inlet sensor **125** is configured to measure the temperature of the CNG flowing into the gas rail **111** from the main line **109** ("Gas Rail Inlet Temperature"). In the embodiments in which the system **100** also includes front and back temperature sensors **127**, **129**, the front temperature sensor **127** may be disposed proximal to the first of the plurality of injectors **106** in the bank **105** and may be configured to measure the temperature of the CNG flowing in the gas rail **111** adjacent to or proximal to such first injector **106***a*. The back temperature sensor **129** may be disposed proximal to the last of the plurality of injectors **106** in the bank **105** and may be configured to measure the temperature of the CNG flowing in the gas rail **111** adjacent to or proximal to such last injector **106***z*.

The gas line sensor **124**, the gas rail inlet sensor **125**, the return coolant sensor **126**, the front temperature sensor **127**, and the back temperature sensor **129** may each be any appropriate sensor that is capable of capturing temperature data and transmitting such data through a communication channel **132** to the controller **112** for processing. The communication channel **132** may be an optical channel, or any other wired, wireless or radio channel or any other type of channel capable of transmitting data between two points.

In some embodiments, the system **100** may also include a flow orifice disposed in the return channel **148**. The flow orifice **131** may be configured to tune the system flow rates and pressures as is known to do in the art.

The controller **112** may include a processor **134** and a memory component **136**. The controller **112** may be operably connected to the injectors **106**, the control valve **110**, the gas line sensor **124**, and the return coolant temperature sensor **126**. In embodiments that include the gas rail inlet sensor **125** and/or the front temperature sensor **127** and the back temperature sensor **129**, the controller may also be operably connected to such elements.

The processor **134** may be a microprocessor or other processor as known in the art. The processor **134** may execute instructions and generate control signals for processing Gas Line Temperature data, Return Coolant Temperature data, determining whether the Gas Line Temperature is in an operating range, determining a Target Return Coolant Temperature, and activating the control valve to control the flow of return fluid, and the like. In embodiments including the pump, the processor may also activate/deactivate the pump. In some embodiments, the processor **134** may execute instructions and generate control signals for controlling the duration of injection by the injectors. Such instructions may be read into or incorporated into a computer readable medium, such as the memory component **136** or provided external to the processor **134**. In alternative embodiments, hard wired circuitry may be used in place of, or in combination with, software instructions to implement a control method.

The term "computer readable medium" as used herein refers to any non-transitory medium or combination of media that participates in providing instructions to the processor **134** for execution. Such a medium may comprise all computer readable media except for a transitory, propagating signal. Common forms of computer-readable media include, for example, a floppy disk, a flexible disk, hard disk, magnetic tape, or any other magnetic medium, a CD-ROM, any other optical medium, or any other medium from which a computer processor **134** can read.

The controller **112** is not limited to one processor **134** and memory component **136**. The controller **112** may be several processors **112** and memory components **114**.

In an embodiment of the system **100** illustrated in FIG. **2**, the control valve **110** may be a three-way valve and the system **100** may also include a pump **140**.

The control valve **110** may be a three-way control valve and may include the first input port **128**, the first output port **130**, and a second output port **142**. The second output port **142** may be configured to emit return coolant into a conduit **144** connecting the second outlet port **142** and the supply channel **146** feeding the pump **140**.

The pump **140** may be disposed on the supply channel **146** between the engine **102** and the heat exchanger **104** and may be operably connected to the controller **112**. The pump **140** may be configured to receive engine coolant from the engine **102** and return coolant from the control valve **110**. In one embodiment the pump **140** may output supply coolant that includes engine coolant and return coolant. In such an embodiment, the return coolant received by the pump **140** may be received from the control valve **110** through the conduit **144**. In another embodiment, the supply coolant output from the pump may only include engine coolant. In some embodiments, the pump **140** may be a variable-flow pump. In other embodiments, the pump **140** may be a constant output pump.

INDUSTRIAL APPLICABILITY

Referring now to FIG. **4**, an exemplary flowchart is illustrated showing sample steps which may be followed in controlling the fuel mass of CNG received by the engine **102** with the embodiment of the system **100** illustrated in FIG. **1**. The method may be practiced with more or less than the number of steps shown and is not limited to the order shown.

Step **300** of the method includes receiving, by the controller **112**, from the gas line sensor **124**, the Gas Line Temperature data that indicates the temperature of the CNG disposed in the (CNG) gas line **108**.

In step **302** includes receiving, by the controller **112**, from the return coolant sensor **126**, Return Coolant Temperature data that indicates the measured temperature of the return coolant proximal to the heat exchanger **104**. In the embodiment of the system illustrated in FIG. **1**, the Return Coolant Temperature data may, more precisely, indicate the temperature of the return coolant (from the heat exchanger **104**) after it has exited the control valve **110** first output port **130**.

In step **304**, the Gas Line Temperature data is processed by the controller **112** to determine whether the Gas Line Temperature (of the CNG) is in an operating range. In some embodiments, this Gas Line Temperature may be determined from the Gas Line Temperature data received from the gas line sensor **124**. In other embodiments, the Gas Line Temperature may be determined as a function of the Return Coolant Temperature or as a function of the Gas Line Temperature data and the Return Coolant Temperature data. The operating range may span a predetermined number of degrees anywhere in the range between about 10° C. and about 90° C. For example, in one embodiment, the operating range may span about 5° C. in the range between about 40° C. to about 45° C. In another embodiment, the operating range may span about 10° C. in the range between about 80° C. to about 90° C. In yet another embodiment, the operating range may be a target Gas Line Temperature, plus or minus ten percent. In yet another embodiment, the operating range may be a target Gas Line Temperature, plus or minus five percent. In yet another embodiment, the operating range may be a target Gas Line Temperature, plus or minus one percent. In yet another embodiment, the operating range may be about the target Gas Line Temperature. In an embodiment, the target Gas Line Temperature may be a temperature between about 10° C. and about 90° C.

If the Gas Line Temperature is not in the operating range, a target Return Coolant Temperature ("Target Return Coolant Temperature") is determined by the processor in step **306**. In one embodiment, the Target Return Coolant Temperature may be determined based on one or more system parameters. For example, in an embodiment, the Target Return Coolant Temperature may be based on system parameters, or the combination of such parameters, as engine speed, the liquid natural gas (LNG) pump flow demand, the supply temperature, and the like. The supply temperature is the temperature of the supply coolant disposed in the supply channel **146**. The processing done by the controller **112** to determine the Target Return Coolant Temperature may be done using, algorithms, look-up tables, mapping, hash tables or the like.

In step **308**, the controller **112** determines if the (measured) Return Coolant Temperature is greater than or equal to the Target Return Coolant Temperature. If yes, the method proceeds to step **310**, if no, the method proceeds to step **312**.

In step **310**, the controller **112** transmits a signal that causes the control valve **110** to either close or restrict the path of the return fluid passing through in the control valve **110** depending on the difference between the (measured) Return Coolant Temperature and the Target Return Coolant Temperature.

In step **312**, the controller **112** transmits a signal that causes the control valve **110** to open or increase the flow of the return coolant through the control valve **110** depending on the difference between the (measured) Return Coolant Temperature and the Target Return Coolant Temperature. The amount the control valve **110** will be opened depends on the difference.

In an alternative embodiment, steps **306** and **308** of the flowchart in FIG. **4** may be omitted. In such an embodiment, if in step **304** the Gas Line Temperature is not in the operating range, the process would proceed to either step **310** or **312** depending on the measured Gas Line Temperature. If the measured Gas Line temperature is higher than desired, the process would proceed to step **310**. If the measured Gas Line Temperature is lower than desired, the process would proceed to step **312**. In a variation of this alternative embodiment, the process may proceed to steps **310** and **312** depending on both the measured Gas Line Temperature and the measured Return Coolant Temperature. If the measured Gas Line Temperature and the Return Coolant Temperature are both higher than desired, than the process would proceed to step **310**. If the measured Gas Line Temperature and the Return Coolant Temperature are both lower than desired, the process would proceed to step **312**.

Referring now to FIG. **5**, an exemplary flowchart is illustrated showing sample steps which may be followed in controlling the fuel mass of CNG received by the engine **102** with the embodiment of the system **100** illustrated in FIG. **2** that includes the three-way control valve **110** and the pump **140**.

The method may be practiced with more or less than the number of steps shown and is not limited to the order shown.

Step **400** of the method includes receiving, by the controller **112**, from the gas line sensor **124**, Gas Line Temperature data that indicates the measured temperature of the CNG (at the gas line sensor **124**) disposed in the CNG gas line **108**.

In step **402** includes receiving, by the controller **112**, from the return coolant sensor **126**, Return Coolant Temperature data that indicates the temperature of the return coolant exiting from the heat exchanger **104**.

Similar to step **304** in FIG. **4**, in step **404** in FIG. **5**, the Gas Line Temperature data is processed by the controller **112** to determine whether the Gas Line Temperature (the temperature of the CNG) is in an operating range. Similar to step **304** in FIG. **4**, the operating range may span a predetermined number of degrees in the range between about 10° C. and about 90° C. In some embodiments, this Gas Line Temperature may be determined from the Gas Line Temperature data received from the gas line sensor **124**. In other embodiments, the Gas Line Temperature may be determined as a function of the Return Coolant Temperature or as a function of the Gas Line Temperature data and the Return Coolant Temperature data.

If the Gas Line Temperature is not in the operating range, a Target Return Coolant Temperature is determined by the processor in step **406**. In one embodiment, the Target Return Coolant Temperature may be determined based on one or more system parameters. For example, in an embodiment, the target Return Coolant Temperature may be based on system parameters, or the combination of such parameters as engine speed, the LNG pump flow demand, the supply temperature, and the like. The processing done by the controller **112** to determine the target return coolant may be done using, algorithms, look-up tables, mapping, hash tables or the like.

In step **408**, the controller **112** determines if the (measured) Return Coolant Temperature is greater than or equal to a predetermined maximum Return Coolant Temperature. If yes, the method proceeds to step **410**, if no, the method proceeds to step **412**.

In step **410**, the controller **112** transmits a signal that causes the three-way control valve **110** to route the path of the return fluid passing through in the control valve **110** such that the return fluid flows out output port **142** and does not flow out the first output port **130**. In other words, the input port **128** and the second output port **142** are connected in a flow path. In this condition, when return fluid flows out output port **142** and does not flow out the first output port **130**, the three-way valve is considered to be "closed". The controller **112** may also transmit a signal that stops operation of the pump **140**.

In step **412**, the controller **112** determines if the (measured) Return Coolant Temperature is greater than or equal to the Target Return Coolant Temperature. If yes, the method proceeds to step **414**, if no, the method proceeds to step **416**.

In step **414**, the controller **112** transmits a signal that causes the three-way control valve **110** to allow a portion of the return coolant flowing through the control valve **110** to flow out of the first output port **130** and the remaining portion to flow out of the second output port **142** into the conduit **144**. In embodiments in which the pump **140** is a variable-flow pump, instead of a constant output pump, the controller **112** may also transmit a signal that causes the pump **140** to increase the flow of supply coolant exiting the pump. This increases the flow of the combination of engine coolant and return coolant entering the heat exchanger **104**.

In step **416**, the controller **112** determines if the engine load is less than an engine load threshold value. If yes, the method proceeds to step **418**. If no, the method proceeds to step **420**.

The controller **112**, in step **418**, transmits a signal that causes the three-way control valve **110** to block the path of the return coolant through the second output port **142** but allow return coolant to flow through the first output port **130**. In this condition, the three-way control valve is considered to be "open". In embodiments in which the pump **140** is a variable-flow pump, instead of a constant output pump, the controller **112** may also transmit a signal that causes the pump **140** to increase the flow of supply coolant exiting the pump **140**.

In step **420**, the controller transmits a signal that causes the three-way control valve **110** to block the path of the return coolant through the second output port **142** but to allow return coolant to flow through the first output port **130**. The controller **112** also transmits a signal that stops the pump **140**.

Referring now to FIG. **6**, an exemplary flowchart is illustrated showing sample steps which may be followed in controlling the fuel mass of CNG received by the engine **102** with the embodiment of the system **100** illustrated in FIG. **2** that includes the three-way control valve **110** and the pump **140**. The method may be practiced with more or less than the number of steps shown and is not limited to the order shown. The method of FIG. **6** is the same as that of FIG. **5** except that step **406** is omitted and step **411** is substituted for step **412**. As such only step **411** will be discussed below.

In step **411**, the controller **112** determines if the Gas Line Temperature is below the operating range. If yes, the method proceeds to step **414**, if the Gas Line Temperature is above the operating range, the method proceeds to step **416**.

Both FIGS. **4-6** may be modified to also include the steps illustrated in FIG. **7**, or alternatively, FIG. **8**. These steps maintain the fuel mass of the CNG received by the engine **100** by adjusting the duration of the injection of CNG into the combustion chamber of the engine in the event that the temperature of the CNG varies either within the operating range or outside of the operating range.

Referring now to FIG. **7**, an exemplary flowchart is illustrated showing sample steps which may be followed in controlling the fuel mass of CNG received by the engine **102** with the embodiment of the system **100** illustrated in either FIG. **1** or **2**. The method may be practiced with more or less than the number of steps shown and is not limited to the order shown.

Step **500** includes receiving, by the controller **112**, gas rail temperature information from the front and back sensors **127**, **129**. In one embodiment, the temperature of the CNG in the gas rail at the front of the bank **105** of injectors **106** may be measured by the front temperature sensor **127** proximal to the first injector **106***a* in the bank **105** of injectors (the "Front Gas Rail Temperature"), and the temperature of the CNG in the gas rail at the rear of the bank **105** may be measured by the back temperature sensor **129** proximal to the last injector **106***z* in the bank **105** (the "Back Gas Rail Temperature").

In step **502**, the controller **112** determines a gas rail temperature at each one of the injectors **106** in the bank **105** as a function of the engine speed, the CNG demand, the relative position of the injector in the bank (first, second, third etc.), and the measured Front and Back Gas Rail Temperatures.

In step **504**, for each injector **106**, the controller **112** selects a CNG Waveform Duration Scaling Factor from a map as a function of the CNG gas rail temperature at the injector **106**.

In step **508**, the controller **112** adjusts the injection duration of each injector **106** based on the CNG Waveform Duration Scaling Factor for the injector **106**.

Alternatively, the fuel mass of CNG received by the engine **102** may be controlled by following the process steps illustrated in FIG. **8** where the temperature of the CNG is measured at the CNG gas rail inlet **113** (instead of at the front and back of the injector bank **105**) and the temperature at each injector is estimated.

Step **600** includes receiving, by the controller **112**, CNG Gas Rail Inlet Temperature information from the gas rail inlet sensor **125**.

In Step **602**, the controller **112**, selects the (estimated) CNG gas rail temperature at the back of the injector bank **105** from a map as a function of engine speed, engine coolant temperature, CNG demand, diesel rail pressure demand, and CNG Gas Rail Inlet Temperature.

In step **604**, the controller **112** determines CNG gas rail temperature at each injector **106** as a function of engine speed, CNG demand, the relative position of the injector cylinder in the bank of cylinders, the measured CNG Gas Rail Inlet Temperature, and the selected (estimated) CNG gas rail temperature at the rear of the injector bank **105**.

In step **606**, the controller **112** selects a CNG Waveform Duration Scaling Factor for each injector **106** from a map as a function of CNG gas rail temperature at the injector **106**.

In step **608**, the controller **112** adjusts the duration of each injector **106** based on the CNG Waveform Duration Scaling Factor.

Also disclosed is a method of controlling the fuel mass of compressed natural gas received by an engine. The method may comprise receiving a Gas Line Temperature for compressed natural gas disposed in a gas line, and maintaining, by a controller operably connected to a control valve, the Gas Line Temperature within an operating range by adjusting the amount of return coolant allowed to flow through the control valve based at least in part on the Gas Line Temperature and a Target Return Coolant Temperature. In an embodiment, the gas line may be disposed between a heat exchanger and the engine, and the heat exchanger may be configured to receive compressed liquid natural gas and supply coolant and to output the compressed natural gas into the gas line and to output return coolant. The control valve may be configured to receive return coolant from the heat exchanger.

Also disclosed is a computer program product. The computer program product may comprise a non-transitory computer usable medium having a computer readable program code embodied therein. The computer readable program code may be adapted to be executed to implement a method for controlling the fuel mass of compressed natural gas received by an engine, the method comprising receiving a Gas Line Temperature for compressed natural gas disposed in a gas line, and maintaining, by a controller operably connected to a control valve, the Gas Line Temperature within an operating range by adjusting the amount of return coolant allowed to flow through the control valve based at least in part on the Gas Line Temperature and a Target Return Coolant Temperature. In an embodiment, the gas line may be disposed between a heat exchanger and the engine, and the heat exchanger may be configured to receive compressed liquid natural gas and supply coolant and to output the compressed natural gas into the gas line and to output return coolant. The control valve may be configured to receive return coolant from the heat exchanger.

The features disclosed herein may be particularly beneficial for use with mining, earth moving, construction or material handling vehicles.

What is claimed is:

1. A method for controlling the fuel mass of CNG received by an engine, the method comprising:

receiving a Gas Line Temperature for CNG disposed in a gas line, the gas line disposed between a heat exchanger and the engine, the heat exchanger configured to receive CLNG and supply coolant and to output the CNG into the gas line and to output return coolant to a control valve;

maintaining, by a controller operably connected to the control valve, the Gas Line Temperature within an operating range by adjusting the amount of return coolant allowed to flow through the control valve based at least in part on the Gas Line Temperature and a Target Return Coolant Temperature; and

pumping supply coolant and a portion of the return coolant to the heat exchanger, wherein the control valve is a three-way valve configured to divert to a pump a portion of the return coolant flowing through the control valve.

2. The method of claim **1**, wherein the operating range spans about 5° C.

3. The method of claim **1**, wherein, the Target Return Coolant Temperature is based on at least one system parameter.

4. The method of claim **1**, wherein the pumping step occurs when a measured Return Coolant Temperature is greater than or equal to the Target Return Coolant Temperature.

5. The method of claim **1**, further comprising varying, by the controller, the duration of injection by the injector to maintain a generally consistent fuel mass of CNG received by the engine, the controller operably connected to the injector.

6. A system for controlling the fuel mass of CNG received by an engine, the system comprising:

a heat exchanger configured to receive CLNG and supply coolant and to output CNG and return coolant;

an injector operably connected to the engine and configured to inject the CNG into the engine;

a gas line disposed between the injector and the heat exchanger, the gas line configured to carry CNG from the heat exchanger to the injector, the CNG in the gas line at a Gas Line Temperature;

a control valve configured to receive return coolant from the heat exchanger and to change the amount of return coolant flowing through control valve;

a conduit extending between the control valve and a pump, wherein the control valve is a three-way valve configured to divert a portion of the return coolant flowing through the control valve to the pump, and the pump is configured to pump supply coolant and the portion of the return coolant to the heat exchanger; and

a controller operably connected to the control valve, the controller configured to maintain the Gas Line Temperature within an operating range by adjusting the amount of return coolant allowed to flow through the control valve based, at least in part, on the Gas Line Temperature and a Target Return Coolant Temperature.

7. The control system of claim **6** wherein the operating range spans about 5° C.

8. The control system of claim **6**, wherein the operating range is about a target Gas Line Temperature.

9. The control system of claim **6**, wherein the Target Return Coolant Temperature is based on at least one system parameter.

10. The control system of claim **9**, wherein the system parameter comprises engine speed.

11. The control system of claim **10**, wherein the supply coolant is received by the heat exchanger from the engine and the system parameter further comprises a supply temperature for the supply coolant.

12. The control system of claim **9**, wherein the system parameter is LNG pump flow demand.

13. The control system of claim **6**, in which the controller is further configured to maintain the Gas Line Temperature within an operating range by adjusting the amount of return coolant allowed to flow through the control valve based, at least in part, on the Gas Line Temperature, a Target Return Coolant Temperature, and a measured Return Coolant Temperature.

14. The control system of claim **6**, in which the heat exchanger includes a first inlet, a first outlet, a second inlet and a second outlet, and the heat exchanger is configured to receive CLNG through the first inlet and supply coolant through the second inlet, the heat exchanger further configured to output CNG from the first outlet, and return coolant from the second outlet.

15. The control system of claim **6**, wherein the controller is further configured to adjust the control valve to divert the portion of the return coolant flowing into the control valve to the pump if a measured Return Coolant Temperature is greater than or equal to the Target Return Coolant Temperature.

16. The control system of claim **15**, in which the controller is further configured to increase the recirculation of the pump if the measured Return Coolant Temperature is greater than or equal to the Target Return Coolant Temperature.

17. The control system of claim **6**, wherein the controller is further configured to open the control valve if an engine load is less than a threshold.

18. A computer program product comprising a non-transitory computer usable medium having a computer readable program code embodied therein, the computer readable program code adapted to be executed to implement a method for controlling the fuel mass of CNG received by an engine, the method comprising:

receiving a Gas Line Temperature for CNG disposed in a gas line, the gas line disposed between a heat exchanger and the engine, the heat exchanger configured to receive CLNG and supply coolant and to output the CNG into the gas line and to output return coolant; and

maintaining, by a controller operably connected to a control valve, the Gas Line Temperature within an operating range by adjusting the amount of return coolant allowed to flow through the control valve based at least in part on the Gas Line Temperature and a Target Return Coolant Temperature, wherein the control valve is configured to receive return coolant from the heat exchanger and to divert a portion of the return coolant flowing through the control valve to a pump, and the pump is configured to pump supply coolant and the portion of the return coolant to the heat exchanger.

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